

## Sustainable postharvest solutions: Enhancing potato quality with whey protein-based edible coatings

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**Abstract:** Postharvest food loss and sustainability are important issues in the storage of potatoes. Edible coatings, specifically whey protein concentrate (WPC), are environmentally friendly options that can be used to maintain quality. This study examined the effectiveness of the WPC coating in ensuring quality in potato tubers when in storage. Potatoes that were fresh, even-sized, and free of defects were divided into three groups: the control (T1), which had no coating; WPC-coated (T2); and composite WPC-coated (T3). The potatoes were stored for 60 days under ambient conditions (25 °C, 55% relative humidity), refrigeration (4 °C), and controlled conditions (20 °C, 74% relative humidity). Sensory assessment was carried out at regular intervals by use of the 5-point hedonic scale. Uncoated tubers (T1) started showing wrinkling and decay on Day 28, and the condition worsened with time under all conditions. On the other hand, the coated potatoes (T2 and T3) stayed smooth and acceptable in appearance until the end of storage. Statistical Analysis showed a significant difference between coated and non-coated potatoes, but not between T2 and T3. It can be concluded from this experiment that coating of potatoes using whey protein concentrate (WPC) is an environmentally friendly way to prolong shelf life.

**Keywords:** Edible coating, Potatoes, Sensory properties.

### 1. Introduction

Postharvest losses in potatoes are a significant global concern, affecting food security, economic stability, and resource efficiency. Potatoes, being one of the most widely cultivated and consumed crops worldwide, are particularly vulnerable to spoilage during storage. Edible coatings have emerged as a sustainable and eco-friendly solution to reduce postharvest losses by maintaining quality and extending shelf life. Among these, whey protein concentrate (WPC), a renewable byproduct of dairy processing, offers unique functional properties, including barrier, antimicrobial, and antioxidant effects, that make it a promising candidate for preserving potato tubers [1].

In connection with the problems confronting the world today, food security has now become an increasingly pressing issue, with numerous crises hanging over the sustainability of the food supply chain. Among the concerns, food wastage, particularly of fruits and vegetables, remains a very relevant issue. Unless innovative and sustainable measures are developed, the problems are estimated to worsen even more. This research examines the use of renewable raw material from agro-food waste in the form of whey protein concentrate (WPC) as a food coating to improve the sensory and preservation properties of

potatoes. With this process, the coated product can be eaten by consumers with less wastage and improved food quality [2-4]. Whey protein food films are economical, biodegradable, environmentally friendly, and beneficial in food storage by controlling gas exchange, preserving a low-oxygen, carbon-dioxide atmosphere that slows down spoilage [3]. This study is about potatoes, the world's fourth most vital food crop after rice, wheat, and maize, and Jordan's second most cultivated crop after wheat [5]. While there are several ways through which potatoes can be stored year-round, they have inherent disadvantages. Chemical treatment, for instance, is toxic to health, while cold storage can lead to sugar increases, resulting in sweetening and undesirable coloration on frying [6]. Likewise, while radiation methods are reliable, they are costly and have negative side effects, such that they are not suitable for use by consumers. Thus, with greater demand for cheap, safe, and effective alternatives, whey-based edible coatings are gaining popularity.

Whey is a byproduct of cheese production during dairy processing and is a voluminous byproduct rich in organic matter. It is an excellent barrier to oxygen, oil, and aroma, especially under low to moderate humidity, and has antimicrobial and antioxidant characteristics, which promote shelf life and food safety [3]. Its chemical composition provides the resistance required for application as a single layer on inhomogeneous foods or as a component of packaging pouches [7, 8]. Whey protein coatings also inhibit moisture and weight loss by reducing respiration rates by managing gas [2, 7, 8]. Whey protein can be utilized as an inexpensive coating material, possessing distinctive benefits such as biodegradability and non-toxicity [9]. To ensure flexibility and avoid brittleness, plasticizers such as glycerol and sorbitol will be used. From a perspective of sustainability, this process is advantageous both in reducing post-harvest losses and in reducing food waste by transforming dairy waste products into viable coating substances. This, in turn, ensures long-term agricultural productivity and market accessibility and finds itself in keeping with consumer needs and environmental goals [2]. This study aims to evaluate the effectiveness of whey protein concentrate (WPC)-based edible coatings, alone or in combination with natural additives, in maintaining the postharvest quality and sensory properties of potatoes under different storage conditions.

## 2. Materials and Method

### 2.1. Selection of Plant Materials and Chemicals

Potatoes of uniform size are purchased from the central vegetable market in Irbid, Jordan. Tubers are visually inspected, and abnormal, rotten, or physically damaged samples are rejected. Chemicals used in the experiment included medium molecular weight chitosan with a deacetylation degree of 75–85% (Sigma-Aldrich), whey protein concentrate (WPC) from Gainland Chemical Company, U.K., coconut oil, glycerol as a plasticizer, Tween 80 (TEDIA Firland, Germany) as an emulsifier, and glacial acetic acid as a preservative. All chemicals used were analytical grade.

### 2.2. Preparation of Edible Coating Solution

The whey protein concentrate (WPC) solution was prepared by dissolving 50 g of WPC in 1000 ml of distilled water, then heating the mixture in a water bath at 80–90°C for 30 minutes to denature the whey protein and improve its film-forming properties. A chitosan solution was prepared by dissolving 5 g of chitosan in 10 ml of distilled water with continuous stirring using a magnetic stirrer. The following ingredients were then added sequentially to the solution: 5 ml of glycerol (to improve flexibility), 5 ml of glacial acetic acid (as a preservative and solvent for chitosan), 1 ml of Tween 80 (as an emulsifier), and 1 ml of coconut oil (as an antimicrobial agent). This formulation aimed to enhance both the mechanical strength and barrier properties of the coating, while also providing antimicrobial activity to improve shelf life.

### 2.3. Application of Coating to Potatoes

Before applying the coatings, the potato tubers were thoroughly washed and dried using absorbent paper. The tubers were then dipped in the coating solutions according to the following treatments: T1

(Control), where no coating was applied; T2, where only whey protein concentrate was used; and T3, where a mixture of whey protein concentrate, chitosan, glycerol, glacial acetic acid, Tween 80, and coconut oil was used. Each potato was immersed in the respective coating solution for 30 seconds, then removed and allowed to air dry for 1.5 hours. The coated tubers were placed on plates, each containing eight pieces. The samples were then stored under three different conditions: in an incubator at  $20 \pm 2^\circ\text{C}$  with 74% relative humidity (RH), in a standard refrigerator, and at room temperature with 55% RH. All samples were stored for 60 days under these conditions.

#### 2.4. Sensory Evaluation

Sensory evaluation was carried out two weeks after the coating application to assess the quality attributes of the potato tubers. The parameters evaluated included color, gloss, texture, odor, and overall acceptability. The evaluation was performed following the method described by Emragi, et al. [10]. A panel of 40 trained judges rated the sensory characteristics of the samples using a 5-point hedonic scale, as shown in Table 1.

**Table 1.**  
Scoring system for evaluating potato visual appearance.

Score	Description
0	Unaffected (fresh appearance, glossy, no wrinkling)
1	Slight wrinkling
2	Moderate wrinkling
3	Severe wrinkling and the beginning of decay
4	Advanced decay, complete texture loss

#### 2.5. Statistical Analysis

The experiments were conducted in triplicate, and values are expressed as mean  $\pm$  standard deviation (SD). The data were subjected to analysis of variance (ANOVA) to determine the impact of treatments and storage conditions on physicochemical and sensory characteristics. Means were compared using Tukey's Honestly Significant Difference (HSD) test in the event of any significant difference ( $p < 0.05$ ) to make multiple comparisons among the treatments. Statistical tests were conducted using SPSS, as it was selected due to its capability to handle experimental data and compare multiple groups effectively.

### 3. Results

#### 3.1. Effect of Whey Protein and Composite Coatings on Visual Appearance at $20 \pm 1^\circ\text{C}$ and 74% RH

The visual appearance of potato tubers stored at  $20 \pm 1^\circ\text{C}$  and 74% RH over 60 days is summarized in Table 2. Uncoated tubers (T1) exhibited initial wrinkling at Day 28, progressing to pronounced wrinkling and decay by Day 42, and significant texture loss by Day 60. In contrast, tubers treated with whey protein concentrate (T2) and the composite coating (T3) maintained an unaffected, glossy surface throughout the storage period. Statistical analysis (ANOVA,  $p < 0.05$ ) indicated significant differences between the coated (T2, T3) and uncoated (T1) samples, while no significant difference was observed between T2 and T3, suggesting that whey protein alone effectively preserved visual quality.

**Table 2.**  
Effect of whey protein coating and composite coating on potato visual appearance during 60 days at  $20 \pm 1^\circ\text{C}$  and 74% RH.

Storage time (days)	Control (T1)	WPC (T2)	Composite (T3)
7	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)
14	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)
28	1.8 $\pm$ 0.4 (b)	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)
42	3.0 $\pm$ 0.3 (c)	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)
60	3.8 $\pm$ 0.2 (d)	0.2 $\pm$ 0.1 (a)	0.1 $\pm$ 0.05 (a)

**Note:** \*Values are expressed as mean  $\pm$  SD ( $n = 3$ ). Different letters in the same column indicate significant differences ( $p < 0.05$ ) according to Duncan's test.\*

### 3.2. Effect of Whey Protein Coating and Composite on Visual Appearance at Room Temperature ( $\sim 25^{\circ}\text{C}$ ) and 55% RH of Potatoes

At room temperature ( $\sim 25^{\circ}\text{C}$ ) and 55% RH, all treatments remained unaffected through Day 14. From Day 28 onward, T1 displayed visible wrinkling and decay, worsening by Day 42–60. Both T2 and T3 maintained surface integrity and glossiness throughout the study (Table 3). ANOVA confirmed that coated samples differed significantly from the control ( $p < 0.05$ ), with no statistically significant difference between T2 and T3.

**Table 3.**

Effect of whey protein coating and composite coating on potato visual appearance during 60 days at room temperature ( $\sim 25^{\circ}\text{C}$ ) and 55% RH.

Storage time (days)	Control (T1)	WPC (T2)	Composite (T3)
7	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)
14	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)
28	2.0 $\pm$ 0.3 (b)	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)
42	3.5 $\pm$ 0.2 (c)	0.1 $\pm$ 0.05 (a)	0.0 $\pm$ 0.0 (a)
60	4.0 $\pm$ 0.0 (d)	0.3 $\pm$ 0.1 (a)	0.2 $\pm$ 0.1 (a)

**Note:** \*Values are expressed as mean  $\pm$  SD ( $n = 3$ ). Different letters in the same column indicate significant differences ( $p < 0.05$ ) according to Duncan's test.\*

### 3.3. Effect of Whey Protein Coating and Composite on Visual Appearance Under Refrigeration ( $\sim 4^{\circ}\text{C}$ ) of Potato

During refrigerated storage at  $4^{\circ}\text{C}$ , all treatments remained visually stable through Day 14. By Day 28, T1 exhibited initial wrinkling and decay, while T2 and T3 remained unaffected, with glossy surfaces (Table 4). By Day 60, T1 showed severe texture loss and wrinkling. Both coated treatments preserved tuber appearance and texture, with no significant difference between T2 and T3 (ANOVA,  $p > 0.05$ ).

**Table 4.**

Effect of whey protein coating and composite coating on potato visual appearance during 60 days under refrigeration ( $\sim 4^{\circ}\text{C}$ ).

Storage time (days)	Control (T1)	WPC (T2)	Composite (T3)
7	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)
14	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)
28	2.0 $\pm$ 0.3 (b)	0.0 $\pm$ 0.0 (a)	0.0 $\pm$ 0.0 (a)
42	3.5 $\pm$ 0.2 (c)	0.1 $\pm$ 0.05 (a)	0.0 $\pm$ 0.0 (a)
60	4.0 $\pm$ 0.0 (d)	0.3 $\pm$ 0.1 (a)	0.2 $\pm$ 0.1 (a)

**Note:** \*Values are expressed as mean  $\pm$  SD ( $n = 3$ ). Different letters in the same column indicate significant differences ( $p < 0.05$ ) according to Duncan's test.\*

## 4. Discussion

### 4.1. Effect of Whey Protein Coating and Composite on Visual Appearance at $20 \pm 1^{\circ}\text{C}$ and 74% RH of Potatoes Over 60 Days

The results demonstrate that whey protein-based coatings, either alone (T2) or as a composite (T3), effectively maintain potato visual quality under ambient conditions. The uncoated tubers (T1) deteriorated due to moisture loss and microbial activity, consistent with prior reports on postharvest senescence [6, 11]. Whey protein forms a cohesive barrier that limits water vapor permeability and oxygen transfer, reducing surface dehydration and microbial growth [12–14]. The similar performance of T2 and T3 indicates that the composite components did not significantly enhance visual protection under these storage conditions. This may be attributed to suboptimal interactions between whey protein and composite additives or uneven dispersion of chitosan and other functional ingredients, which could limit their synergistic effects [15, 16]. Nonetheless, composites may offer advantages not captured in visual assessment alone, such as increased flexibility or broader antimicrobial efficacy [15–17]. Compared

with previous studies, these findings confirm that whey protein coatings alone can sufficiently maintain potato appearance under moderate ambient conditions, aligning with literature reporting that composites often provide only marginal improvements unless optimized [18-21].

#### *4.2. Effect of Whey Protein Coating and Composite on Visual Appearance at Room Temperature (~25 °C) and 55% RH of Potatoes Over 60 Days*

Under room conditions, T2 alone effectively preserved tuber appearance, with T3 performing similarly. While chitosan and other additives in T3 are known to enhance barrier and antimicrobial properties [21, 22], the composite did not outperform T2 in this study. Potential explanations include suboptimal ratios of plasticizers or emulsifiers affecting film uniformity and limited chitosan distribution, reducing efficacy [23]. Ambient microbial loads may also have been insufficient to reveal performance differences between coatings. These findings align with literature showing whey protein coatings' ability to retain moisture and delay senescence in perishable produce [18, 20]. From a practical perspective, this suggests that simple WPC coatings can be a cost-effective, efficient solution for maintaining potato quality under standard room conditions, while composites may be more relevant under higher microbial pressure or variable storage conditions.

#### *4.3. Effect of Whey Protein Coating and Composite on Visual Appearance Under Refrigeration (~4 °C) of Potato Over 60 Days*

Refrigerated storage further highlights the protective role of whey protein coatings. T2 and T3 maintained an unaffected, glossy surface over 60 days, while T1 deteriorated progressively. The effectiveness is attributed to whey protein's film-forming, moisture-barrier, and gas-barrier properties, which reduce water loss, respiration, and microbial proliferation [1, 22]. Although T3 did not show statistically significant improvement over T2 under refrigeration, composite coatings may provide advantages under more challenging conditions, such as extended storage, temperature fluctuations, or higher microbial loads. These results emphasize that the efficacy of composite coatings depends on both formulation and storage context, consistent with prior research on edible films in postharvest preservation [14, 15, 18].

#### *4.4. Practical Implication*

Overall, the study confirms that whey protein coatings, either alone or in composite form, are effective, food-grade solutions for extending potato shelf life. From a practical standpoint, these coatings can reduce postharvest losses, maintain sensory quality, and contribute to sustainable food-handling practices. Future research should focus on:

- Optimizing composite formulations to enhance synergy between whey protein and additives.
- Investigating microstructural properties, mechanical strength, and antimicrobial efficacy.
- Assessing performance under long-term storage, temperature fluctuations, and industrial-scale application.
- Conducting cost-benefit analyses to evaluate the economic feasibility of composite versus single-component coatings.

## **5. Conclusion**

This study demonstrated that edible coatings derived from whey protein concentrate (WPC), either alone or in combination with natural additives such as chitosan, glycerol, coconut oil, and acetic acid, can significantly improve the postharvest quality and shelf life of potato tubers. Among the treatments tested, the composite coating (T3) was the most effective in preserving the sensory attributes, particularly texture, color, and gloss, under all storage conditions, especially at 20° C and 74% relative humidity. The coatings acted as effective semi-permeable barriers, reducing moisture loss, delaying wrinkling, and minimizing oxidative changes. These improvements not only maintain the visual and sensory appeal of

potatoes but also suggest the potential of such coatings to reduce food waste and enhance sustainability in the food supply chain. Furthermore, utilizing agro-industrial by-products like whey offers an environmentally friendly and cost-effective solution for improving the quality and longevity of fresh produce. Overall, edible coatings based on WPC present a promising alternative to conventional preservation methods and hold potential for broader applications in the postharvest handling of perishable crops.

### Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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